

Maritime In Situ Sensing Inter-Operable Networks (MISSION)

Joseph Rice
Naval Postgraduate School
Monterey, CA 93943

phone: (831) 524-4488 fax: (831) 656-2834 email: jarice@nps.edu

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LONG-TERM GOAL

This research is creating acoustic communications (acomms) technologies enabling underwater sensor networks and distributed systems.

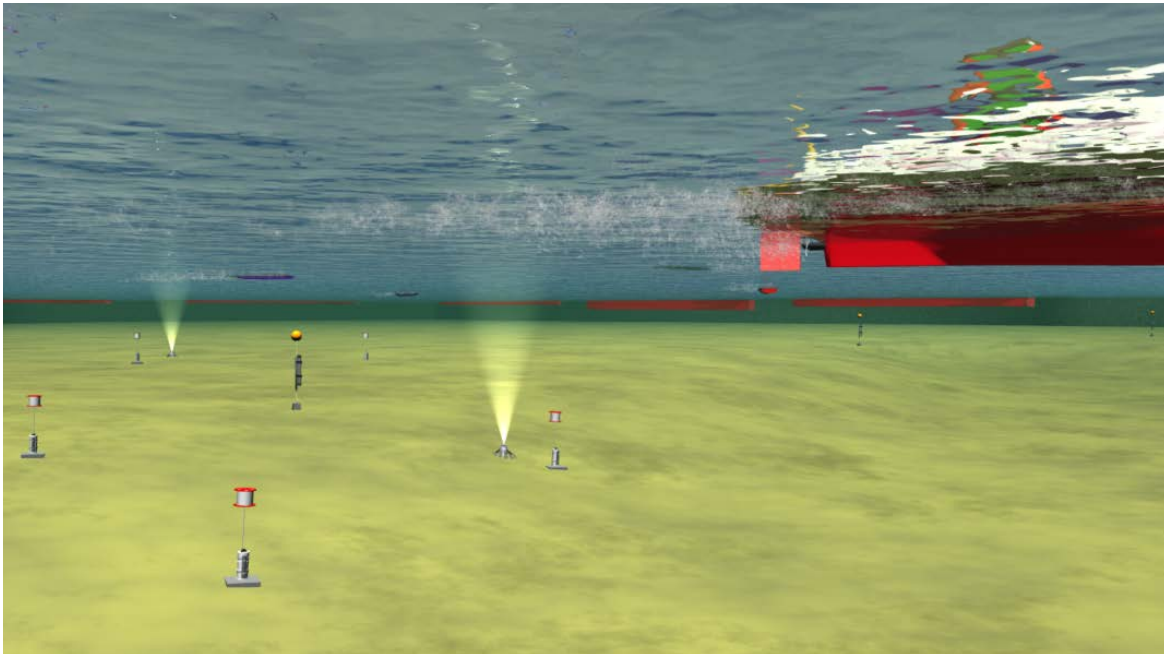


Figure 1. Project MISSION involves the collaborative testing of NPS Seaweb and NUS Unet underwater acoustic networks in the shallow (15-40 meter), noisy waters of Singapore Strait. MISSION experiments were conducted in October 2012 and November 2013.

OBJECTIVES

Project MISSION has the following objectives:

- Study noisy underwater environments.
- Achieve acomms through adverse channels.

- Obtain datasets for acommms channel studies and transmission security (TRANSEC) studies.
- Integrate U.S. Seaweb and Singapore Unet networks.
- Demonstrate acoustic networks in Singapore Strait.

APPROACH

Project MISSION is formally established by Navy International Programs Office (NIPO) and Office of Naval Research (ONR) for collaborative research by the Naval Postgraduate School (NPS) Consortium for Robotics and Unmanned Systems Education & Research Program (CRUSER) and National University of Singapore (NUS) Acoustic Research Laboratory (ARL). ONR 32 and CRUSER each provide matching funds for the U.S. MISSION activities, and Singapore Ministry of Defence (MINDEF) sponsors the Singapore national participation. Moreover, Singapore is hosting the MISSION experiments in Singapore Strait and is providing ship support, logistical support, and environmental compliance support.



Figure 2. Faculty and students perform acoustic communications experiments in Del Monte Lake on the NPS campus and in adjacent Monterey Bay.

In keeping with the CRUSER charter, the CRUSER investment in Project MISSION is directed toward education and research on the NPS campus, including test instruments, on-campus Seaweb laboratories, on-campus test site at Del Monte Lake, project-relevant labor and travel, student research, and conference participation. The ONR funds issued to NPS largely cover the contributions by contractors Teledyne Benthos, Inc. and Liquid Robotics, Inc., and engineering support by SPAWAR Systems Center Pacific.

With cooperation by the Physics Department and the USW Research Center, Project MISSION established the NPS Seaweb Lab in Spanagel Hall. A series of in-water experiments performed in Del Monte Lake and in Monterey Bay have supported student thesis research and Seaweb engineering tests. In addition, a May 2012 acoustic survey jointly conducted by NPS and NUS in Singapore Strait established baseline metrics for MISSION experimentation in that challenging environment.

WORK COMPLETED

A longstanding issue with underwater networks is the vulnerability of moored gateway nodes at the sea surface. Project MISSION is exploring the feasibility of using an Unmanned Surface Vehicle (USV) as the gateway node. The Seaweb Lab has acquired two Wave Glider USVs as experimental platforms for the advancement of a station-keeping, unmoored gateway node to provide the critical interface between the Seaweb underwater domain and the above-water Iridium satellite domain. LT Tim Rochholz, USN, considered the practicality of persistent station keeping by the Wave Glider against the external forces of ocean currents and wind. To gain insight, he followed the progress of 4 Wave Gliders during the first leg (California to Hawaii) of the historic PacX trans-oceanic crossing. ENS Joe Beach, USN, studied the engineering tradeoffs arising from the addition of an acoustic modem to a Wave Glider USV. He considered the impact of hydrodynamic drag and the acoustic performance of the modem for candidate locations on the Wave Glider USV. NPS has collaborated with industry partners Liquid Robotics, Inc. and Teledyne Benthos, Inc. to develop a towed acoustic modem integrated with Wave Glider electronics and Iridium modem.

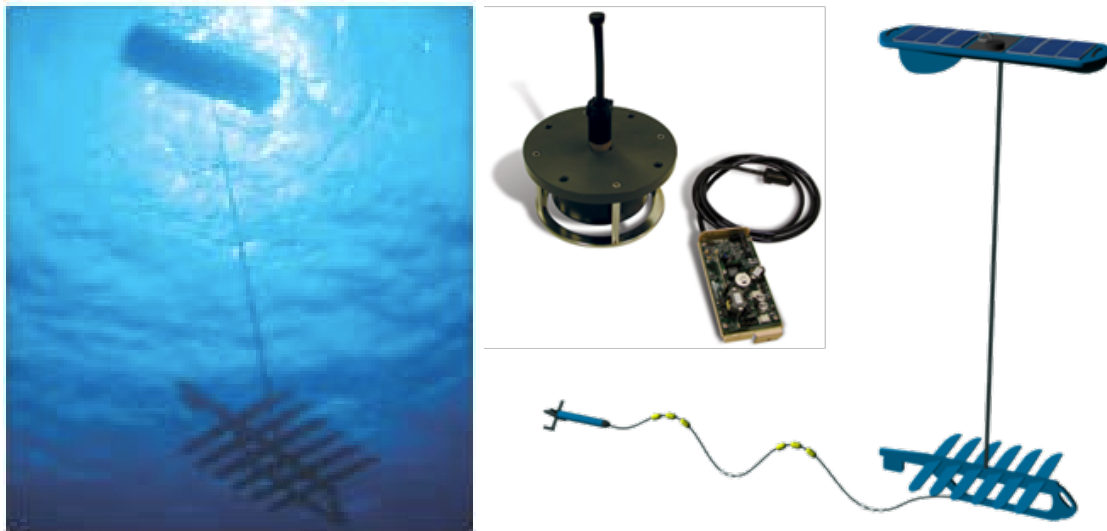


Figure 3. The Wave Glider USV (left) converts vertical sea surface motion into forward thrust. It captures solar energy to power on-board navigation, sensing and communications. Project MISSION has integrated an acoustic modem (electroacoustic transducer and electronics board shown) with a tow body compliantly attached to the lower body of the Wave Glider (right). The resulting “gatekeeper” station-keeping gateway node provides the critical communications interface between the underwater Seaweb network domain and the space-borne Iridium satellite communications domain.

Project MISSION acquired a pair of modem-recorder instruments incorporating a digital recorder with an acoustic modem to facilitate acoustic data acquisition and in situ underwater signaling measurements. Secure Digital (SD) memory cards, electronics, and battery pack are housed in a pressure-tolerant glass sphere with a penetration for the cylindrical electroacoustic transducer. These modem-recorders are useful for performing controlled soundings of the acoustic channel. Acoustic modems in the network are commanded to transmit a suite of experimental waveforms and channel probe signals following an experimental method known as Signalex involving parametric analysis of signals and careful measurement of environmental factors. Signalex transmissions are received and recorded by the modem-recorder instruments and enable analysis of the channel scattering function and link margin. Such in situ measurements are supporting the development of physics-based propagation models, adaptive modulation, and TRANSEC.



Figure 4. Modem-recorders are housed in pressure-tolerant glass spheres for deployment at depth. Received acoustic signals are digitally recorded to removable SD cards for later analysis.

Project MISSION permits researchers to study noisy and variable acomm channels, perform collaborative studies, and conduct long-duration in situ measurements. The Seaweb Lab, Wave Glider USVs, Del Monte Lake, modem-recorders, and the pre-existing inventory of Seaweb acoustic modems and underwater sensors are providing the basis for MISSION experiments in Singapore Strait during October 2012 and November 2013. The MISSION experiments provide opportunities to test channel-tolerant and channel-adaptive acoustic communications, and enable the project team to conduct controlled signaling experiments in acoustically challenging and operationally relevant littoral environments.

Singapore is a challenging environment for underwater communications because of irregular bathymetry, reflective coral reefs, tidal currents, shipping, and impulsive biological noise from snapping shrimp. NUS has developed underwater modems that have been optimized for performance in Singapore waters. These modems provide short-range links in a local-area network (LAN) to complement the Seaweb medium-range modems in a wide-area network (WAN). An experimental goal of the MISSION collaboration is to demonstrate interoperable communications between a Singapore Unet LAN nested within a U.S. Seaweb WAN.

Additionally, NPS is party to a NATO Joint Research Project (JRP) advancing Next-Generation Autonomous Systems (NGAS) for Anti-Submarine Warfare (ASW) surveillance. Through the NGAS JRP, Project MISSION participated in a 2-week sea trial in Oslo Fjord, Norway during October 2012 and in a 2-week trial in Halifax Harbor, Canada during September 2013. These international sea trials in diverse environmental conditions exercised U.S. Seaweb technology as the underlying communications network integrating a heterogeneous set of experimental underwater ASW surveillance sensors being developed by NATO partners Defence R&D Canada (DRDC Atlantic), Germany Federal Armed Forces Underwater Acoustic and Marine Geophysics Research Institute (FWG), Norway Defence Research Establishment (FFI), and U.S. Space & Naval Warfare Systems Center (SSC Pacific).

RESULTS

Project MISSION has advanced through-water acoustic communications and networking capability with emphasis on cross-nation interoperability in noisy littoral environments.

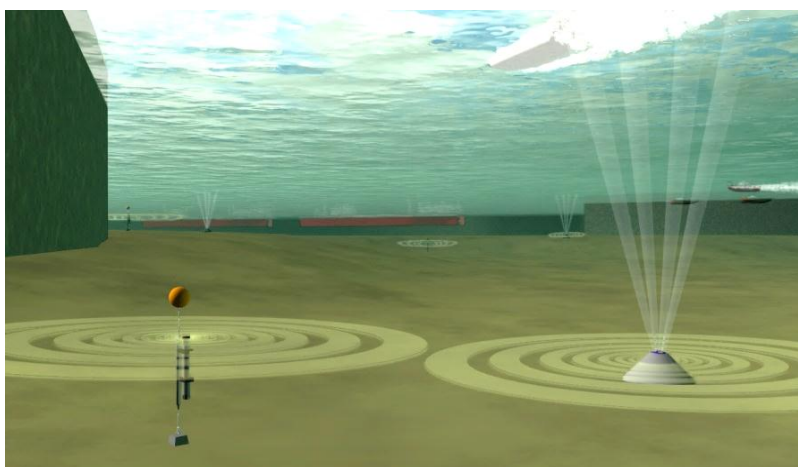


Figure 5. Maritime In Situ Sensing Inter-Operable Networks (MISSION) deliver near-real-time data from distributed underwater sensor stations.



Figure 6. The site for MISSION 2012 and 2013 sea trials is a waiting basin for container ships adjacent to the port of Singapore (background waters), and the Singapore Strait (foreground), a vital sea lane connecting the Indian and Pacific Oceans. The NUS Research Vessel Galaxea supports all aspects of testing.

NPS and NUS performed the 3-week MISSION 2012 trial in Singapore Strait during October 2012. MISSION 2012 achieved the following objectives:

- Operated 10-node Seaweb WAN in noisy, high-current waters for duration of trial.
- Exercised linear network with 8 hops and 556-byte data packets.
- Deployed data-recording telesonar testbed as a surrogate interceptor.
- Recorded 24 hours of intensive network activity for link margin and TRANSEC analysis.
- Performed network discovery and autonomous initialization of network routes.
- Operated 5-node Unet LAN.
- Tested Unet modem software.
- Evaluated ranging performance.
- Measured variability of acommms channel (eigenray propagation and noise).
- Observed in-band ambient noise and its relationships to external factors (diurnal cycle, rain, wind, shipping, etc.).

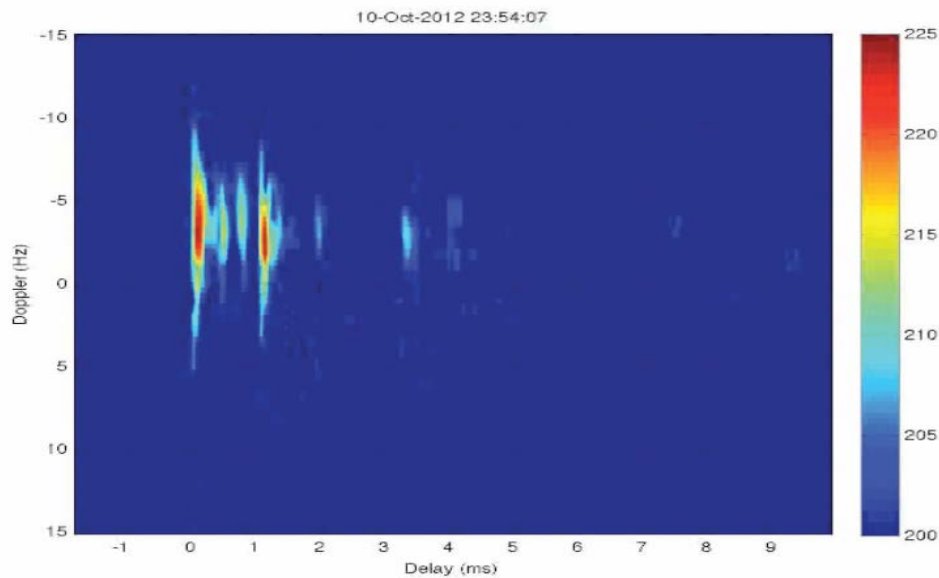


Figure 7. Instantaneous channel response observed at MISSION 2012 is represented by the channel scattering function. The transmitted signal is spread in time by multipath and scattering. The received delay is represented by the x-axis of the channel scattering function. The transmitted signal also experiences Doppler spread, represented by the y-axis, imparted largely by the moving sea surface. The example shown features 2 dominant multipaths and significant Doppler spread. MISSION data recorded in Singapore Strait exhibit time-varying channel scattering functions that impair communications in terms of energy spread and inter-symbol interference. The underwater acoustic channel must be well understood in the design of channel-tolerant or channel-adaptive modulation.

MISSION 2013, the second in the series of bilateral experiments involving NUS and NPS, extends the state of the art of underwater acoustic channel measurements, acomms, and networking. The U.S. objectives at MISSION 2013 include:

- Exercise and stress Seaweb network containing at least 10 fixed nodes.
 - Demonstrate autonomous discovery, ranging, and routing.
 - Exfiltrate large (4-kByte) data packets from distant source node via multi-hop route to gateway node for extended periods (overnight and weekends).
 - Record acoustic network activity for TRANSEC studies.
 - Optimize link-layer timers, MMP, binary and ASCII data packets, Word utility packets.
 - Stress network capacity with multiple source nodes to test Neighbor-Sense Multiple Access (NSMA) collision avoidance.
 - Characterize and document any instances of modem reboots.
- Obtain comprehensive networking data sets.
 - Synchronize Seaweb nodes at start of test; measure clock drift at end of test.
 - Log all modem comms internally.
 - Log all comms at server.
 - Compile comms statistics (packet size, SNR, AGC, RTS attempts, SRQ attempts, dropped packets, network latency).
- Implement NPS Seaweb and NUS Unet gateway nodes at barge.
 - Co-locate Seaweb and Unet transducers on a shared frame.
 - Install independent gateway node cabling, electronics, and user interfaces.
- Demonstrate USA:SIN interoperability.
 - Implement Application Programming Interface (API) at topside workstations.
 - Pass data packets from Singapore LAN to Seaweb WAN.
 - Pass data packets from Seaweb WAN to Singapore LAN.
- Implement Seaweb server improvements.
 - Exercise ASCII and binary messaging.
 - Upgrade time-stamped database of network activity.
 - Improve Graphical User Interface (GUI).
- Model acomms propagation using Bellhop ray physics, range-dependent bathymetry, and measured sound-speed profiles.
- Perform Signalex data collection.
 - At least 10 transmit locations.
 - At least 2 receive locations.

- For environmental noise studies.
- For channel multipath characterization and statistical stationarity studies.
- Updated “autobaud” command for automated transmission of standard modulations.
- Experimental waveforms (.wav files) in the 9-14 kHz band.
- For power-control studies (6.1).
- For adaptive-modulation studies (6.1).
- For TRANSEC studies (6.2).
- Test network routing involving mobile gateway.
 - Use a drifting vessel with deck box and Seaweb server as a surrogate USV.
 - Exploit tidal current for drifting gateway platform.
 - Demonstrate cellular addressing and cell handoff as mobile gateway migrates from cell to cell.
 - Single and dual gateway operations.
- Demonstrate hardware and operations to interested visitors.

The Singapore objectives at MISSION 2013 include the following:

- Study underwater noisy environments.
 - Measure variability in acoustic channel using probe signals.
 - Perform in situ delay-Doppler analysis.
- Achieve communications through adverse channels.
 - Test link tuning algorithms & implementation.
- Integrate NPS Seaweb and NUS Unet networks.
- Demonstrate in situ environmental and surveillance sensor networks in Singapore straits.
 - Test ship tracking capability of network.
- Enable distributed wireless architectures for maritime domain awareness and undersea warfare.
 - Test automated network route discovery.
 - Test automated network self-localization.
 - Test navigation, tracking & communication to STARFISH over Unet network.
- Collect environmental data on tides, currents, waves, temperature, salinity and ambient noise.
 - Environmental data collection.
- Develop shallow-water acomms model for experiment site.
 - Validate acoustic modeling with experimental data.

- Develop 3D particle-tracking module to predict trajectories of mobile nodes.
 - Collect data for testing of AUV motion model based on currents.
- Test energy-efficient mission planning.
 - Collect current data for energy-efficient mission planning.
 - Test energy efficient mission planning using STARFISH.
- Test advanced Unet algorithms, modulations and protocols.
 - Test FH-BFSK performance of Unet modems.
 - Collect data for sparse equalization of single carrier and multi-carrier communications.
 - Test partial FFT based OFDM.
 - Test network coding based broadcasts.
 - Test Doppler estimation and compensation.
 - Test J-ARQ performance.
 - Test super TDMA implementation.
 - Test remote file transfers.
- Test MACA and ALOHA-ACS performance.

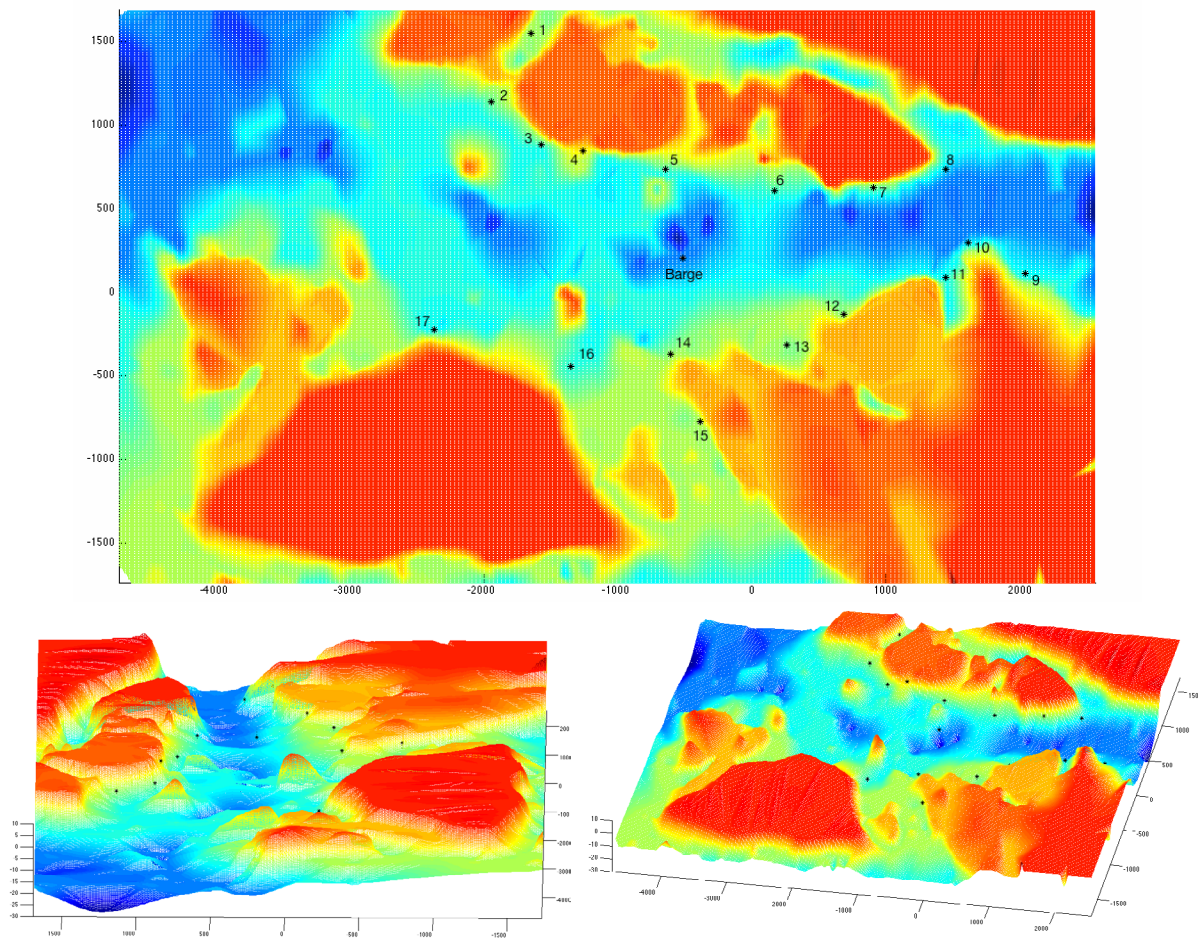


Figure 8. Underwater network nodes at MISSION 2013 are deployed at 18 stations approved by the Singapore coast guard (MPA). These are shown with respect to water depth in plan view (above) and in perspective views from west and south (below left and right, respectively).

IMPACT/APPLICATIONS

Maritime Domain Awareness (MDA) and Undersea Warfare (USW) are national security imperatives that can be served by the deployment of underwater autonomous sensors and systems. Project MISSION is advancing acomms and networking technology to enable such underwater distributed wireless architectures. Project MISSION is emphasizing operations in noisy littoral environments and is fostering cross-nation interoperability.

Project MISSION concludes December 31, 2013. It leaves an unprecedented archive of acomms and underwater networking data for use in future studies of channel variability, adaptive modulation, TRANSEC, and the effective application of acoustic communications networking to achieve distributed underwater systems. Moreover, direct participation in these experiments has significantly advanced the state of art of U.S. Seaweb and Singapore Unet underwater networked communications.

TRANSITIONS

NPS Project MISSION investigators are contributing knowledge and technology to various U.S. Naval programs, including the Deep Seaweb JCTD, the PMW 770 Undersea Connectivity Roadmap, and the OPNAV N2/N6 Undersea Distributed Network.

RELATED PROJECTS

- Through the NGAS JRP, this project collaborates with NATO Undersea Research Centre (NURC), Defence R&D Canada - Atlantic (DRDC Atlantic) (CAN), Norwegian Defence Research Establishment (FFI) (NOR), Office of Naval Research (ONR) (U.S.), Italian Navy (ITN), SPAWAR Systems Center Pacific (SSC Pacific) (U.S.), Defence Science and Technology Laboratory (DSTL) (UK), Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik (FWG) (GER).
- In partnership with SSC Pacific and Applied Research Laboratories University of Texas (ARL:UT), this project supports several programs, including ONR Operational Adaptation Program, OSD Rapid Reaction Technology Office (RRTO), and OPNAV Navy Irregular Warfare Office (NIWO).
- This project incorporates products of SBIR topics N93-170 (telesonar modems), N97-170 (telesonar networking), N99-011 (telesonar directional transducer), N03-224 (telesonar modem), N05-077 (Gatekeeper station-keeping gateway buoy), and SOCOM06-013 (through-modem sensor).

REFERENCES

- “Memorandum of Agreement (MOA) between U.S. DoD and ROS MINDEF for RDT&E Projects,” effective 21 February 2003 through 21 February 2013, NIPO.
- “Project Agreement to the MOA between U.S. DoD and ROS MINDEF for RDT&E, Project Agreement No. N-11-0001 Between The Department of Defense of the United States of America And The Ministry of Defence of the Republic of Singapore Concerning Seaweb Experiment in the Port of Singapore,” NIPO.
- “Summary Statement of Intent (SSOI) for International R&D Agreement,” NIPO.

PUBLICATIONS

MS Theses

- [1] ENS Joseph N. Beach, USN, *Integration of an Acoustic Modem onto a Wave Glider Unmanned Surface Vehicle*, MS thesis, Applied Physics, Naval Postgraduate School, Monterey, CA, Advisor: J. Rice, June 2012
- [2] ENS Rebecca E. King, USN, *Underwater Acoustic Network as a Deployable Positioning System*, MS thesis, Applied Physics, Naval Postgraduate School, Monterey, CA, Advisor: J. Rice, 2nd Reader: G. Clark, June 2012

- [3] LCdr Pascal Gagnon, Canada, *Clock Synchronization through Time-Variant Underwater Acoustic Channels*, MS thesis, Engineering Acoustics & Electrical Engineering (dual degrees), Naval Postgraduate School, Monterey, CA, Co-Advisors: J. Rice, G. Clark, R. Cristi, September 2012
- [4] LT Timothy W. Rochholz, USN, *Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks*, MS thesis, Applied Physics, Naval Postgraduate School, Monterey, CA, Co-Advisors: J. Rice, T. Chung, September 2012
- [5] LT Andrew Hendricksen, USN, *The Optimal Employment and Defense of a Deep Seaweb Acoustic Network for Submarine Communications at Speed And Depth using a Defender-Attacker-Defender Model*, MS Operations Research, Naval Postgraduate School, Monterey, CA, Co-Advisor: M. Carlyle, J. Rice, September 2013
- [6] ENS Murat Aydogmus, Turkish Navy, *Multi-Receiver Acoustic Communications in Time-Varying Underwater Channels*, MS Engineering Acoustics and MS Electrical Engineering (dual degree), Naval Postgraduate School, Monterey, CA, Co-Advisors: R. Cristi and J. Rice, June 2014

Publications & External Presentations

- [1] J. Rice, G. Wilson, M. Barlett, “Deep Seaweb 1.0 Maritime Surveillance Sensor Network,” NDIA 2012 Joint Undersea Warfare Technology Spring Conference, Undersea Sensors technical track, San Diego, CA, March 26-29, 2012
- [2] J. Rice, “Node Ranging, Localization and Tracking as Functions of Underwater Acoustic Networks,” *Proc. Acoustics 2012 Hong Kong*, p. 91, May 13-18, 2012
- [3] M. Chitre, A. Mahmood, and M. Armand, “Coherent communications in snapping-shrimp dominated ambient noise environments,” *Proc. Acoustics 2012 Hong Kong*, vol. 131, p. 3277, May 2012
- [4] J. Rice, C. Fletcher, B. Creber, B. Marn, S. Ramp, F. Bahr, “Implementation of an Underwater Wireless Sensor Network in San Francisco Bay,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey, CA, May 7-10, 2012
- [5] P. Gagnon, J. Rice, G. Clark, “Channel Modeling and Time-Delay Estimation for Clock Synchronization Among Seaweb Nodes,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey, CA, May 7-10, 2012
- [6] R. E. King, “Localization of a Mobile Node in an Underwater Acoustic Network,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey, CA, May 7-10, 2012
- [7] R. Otnes, “NILUS – An Underwater Acoustic Sensor Network Demonstrator System,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey, CA, May 7-10, 2012
- [8] J. Rice, “Project MISSION – Maritime In Situ Sensing Inter-Operable Networks,” *Proc. 10th International Mine Warfare Technology Symposium*, Monterey, CA, May 7-10, 2012

- [9] T. Rochholz, "Wave-Powered Unmanned Surface Vehicle Operation in the Open Ocean: A Station Keeping Asset for Distributed Netted Systems; PAC X: Transpacific Crossing of Wave Glider USVs," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey, CA, May 7-10, 2012
- [10] J. Rice, "Weaponized Underwater Surveillance Network," *Proc. 10th International Mine Warfare Technology Symposium*, Monterey, CA, May 7-10, 2012
- [11] D. Green, "ACOMMS Based Sensing, Tracking, and Telemetry," *Proc. 3rd WaterSide Security Conf.*, Singapore, May 28-30, 2012
- [12] J. Rice, C. Fletcher, B. Creber, B. Marn, S. Ramp, F. Bahr, "Implementation of an Underwater Wireless Sensor Network in San Francisco Bay," *Proc. 3rd WaterSide Security Conf.*, Singapore, May 28-30, 2012
- [13] J. Rice, "Seaweb Subsurface Sensor Network for Port Surveillance and Maritime Domain Awareness," *NMIO Technical Bulletin*, National Maritime Intelligence-Integration Office, Summer 2012 issue, Vol. 3, pp. 10-14, August 2012
- [14] P. Gagnon, J. A. Rice, G. A. Clark, "Clock Synchronization through Time-Variant Underwater Acoustic Channels," *Proc. NATO Underwater Communications Conference (UComms)*, Sestri Levante, Italy, September 12-14, 2012
- [15] M. Chitre, "What is the Impact of Propagation Delay on Network Throughput?" *Proc. NATO Underwater Communications Conf. (UComms)*, Sestri Levante, Italy, Sept 12-14, 2012
- [16] T. W. Rochholz, "Wave-Powered Unmanned Surface Vehicle as a Station-Keeping Gateway Node for Undersea Distributed Networks," presented at NDIA Undersea Warfare Technology Conference, Groton, CT, September 24-27, 2012
- [17] A. Mahmood, M. Chitre, and M. Armand, "Improving PSK performance in snapping shrimp noise with rotated constellations," *Proc. WUWNet'12: 7th ACM International Conference on Underwater Networks & Systems*, Los Angeles, CA, pp. 1-8, November 2012
- [18] M. Chitre, "Teamwork among marine robots - advances and challenges," *Proc. WMR2013 - Workshop on Marine Robotics*, Las Palmas de Gran Canaria, Spain, February 2013
- [19] "Underwater Networking: Captain Nemo goes online," *The Economist Magazine*, March 9, 2013
- [20] J. Rice and M. Chitre, "Maritime In Situ Sensing Inter-Operable Networks involving Acoustic Communications in the Singapore Strait," *CRUSER Continuum*, Monterey, CA, April 9, 2013
- [21] J. Rice and M. Chitre, "Maritime In Situ Sensing Inter-Operable Networks involving Acoustic Communications in the Singapore Strait," *ONR Ocean Acoustics Review*, Bay St. Louis, MS, April 24, 2013
- [22] M. Chitre, I. Topor, R. Bhatnagar and V. Pallayil, "Variability in link performance of an underwater acoustic network," *Proc. IEEE Oceans Conf.*, Bergen, Norway, June 2013

- [23] S. Shankar and M. Chitre, "Tuning an underwater communication link," *Proc. IEEE Oceans Conf.*, Bergen, Norway, June 2013
- [24] R. Otnes and J. Rice, "Underwater acoustic sensor networking in NGAS 2012 sea trial at Oslo Fjord, Norway," *Proc. 1st Underwater Acoustics Conf.*, Corfu, Greece, June 28, 2013
- [25] J. Rice, "MISSION 2013 summary of results," presentation at CRUSER monthly meeting, Monterey, CA, Dec. 11, 2013

HONORS/AWARDS/PRIZES

- T. W. Rochholz, LT USN, SSC Pacific Research Fellowship (\$7400 award), December 2011
- R. E. King, SSC Pacific Research Fellowship (\$5000 award), December 2011
- J. N. Beach, Ensign, USN, NPS Master of Science degree in Applied Physics, June 2012
- R. E. King, Ensign, USN, NPS Master of Science degree in Applied Physics, June 2012
- R. E. King, NPS Degree with Distinction Award, June 2012
- P. Gagnon, LCdr, Royal Canadian Navy, NPS Master of Science degree in Engineering Acoustics, September 2012
- P. Gagnon, LCdr, Royal Canadian Navy, NPS Master of Science degree in Electrical Engineering, September 2012
- P. Gagnon, NPS Degree with Distinction Award, September 2012
- P. Gagnon, NPS Outstanding Thesis Award, September 2012
- T. W. Rochholz, LT, USN, NPS Master of Science degree in Applied Physics, September 2012
- T. W. Rochholz, CNO Undersea Warfare Award, September 2012
- A. Hendricksen, LT, USN, NPS Master of Science degree in Operations Research, September 2013